MODULE 1B

PALUDICULTURE: A PRODUCTIVE USE OF PEATLAND RESTORATION

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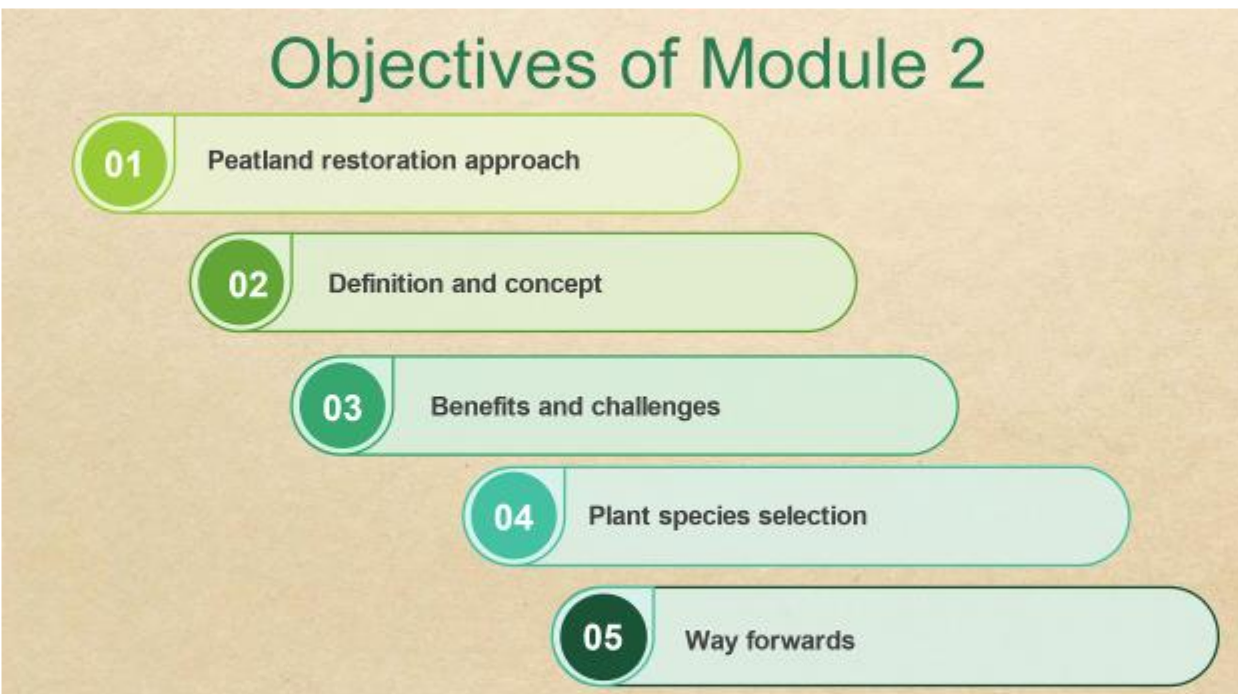
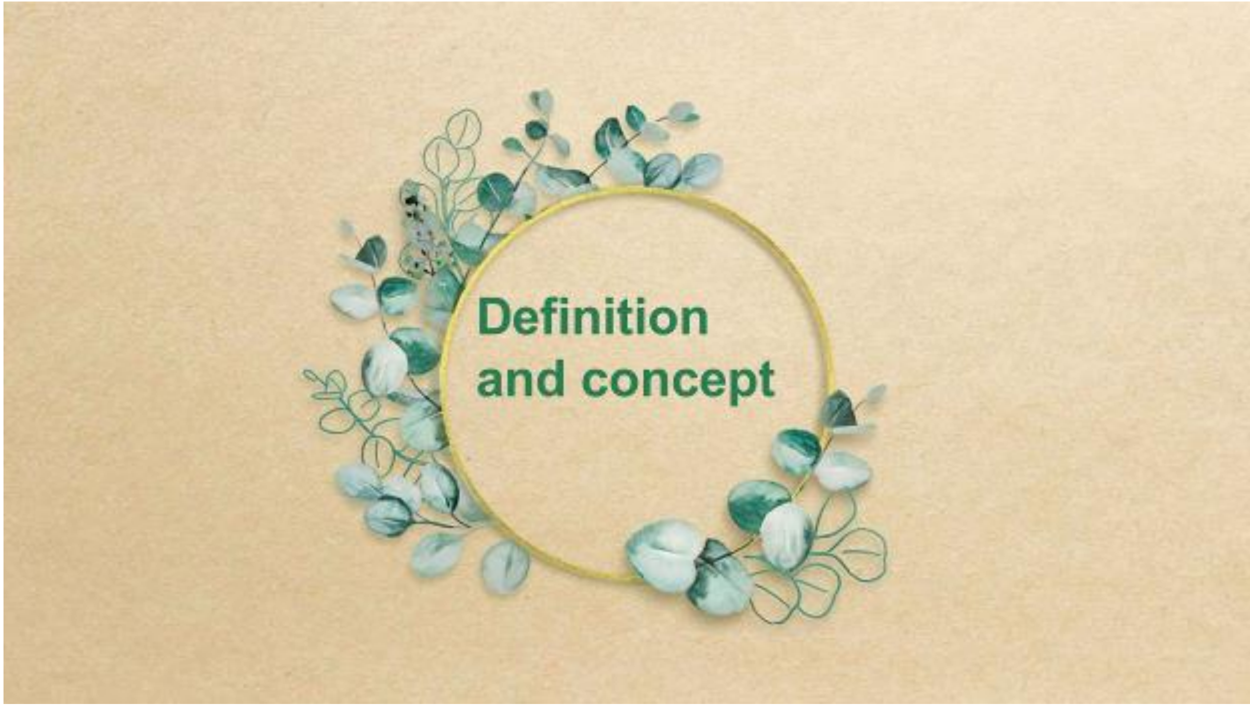


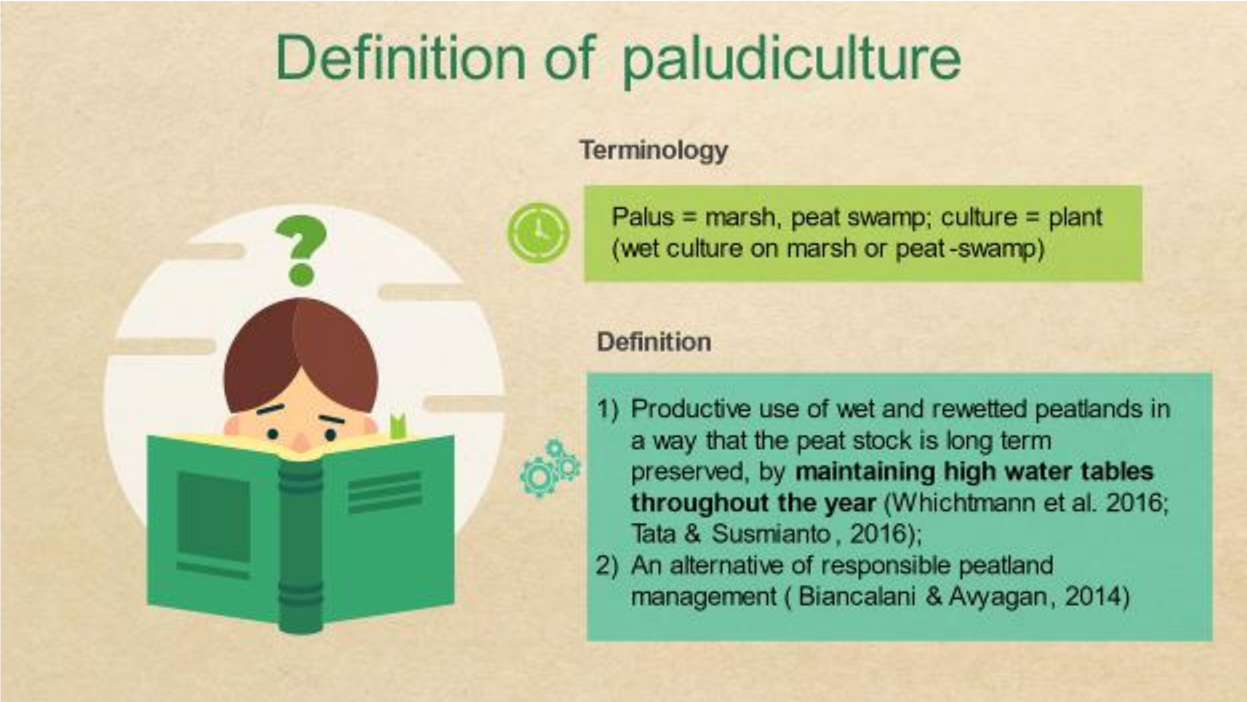
This training focuses on the definition of paludiculture as productive use of peatland restoration. In this training the audience will learn about:

1. Petland restoration approach
2. Definition and concept of paludiculture
3. Benefits and challenges
4. Plant species selection
5. Way forwards

To restore degraded peatlands, Indonesia uses a 3R-approaches, e.g. Rewetting, Revegetation, and Revitalization of livelihoods.
Rewetting is necessary to keep the peatland wet. But please be aware, that wet means to keep the water table as high as the peat-surface.
High water exceeds 10 cm consider as flooding, and methane emission will increase.
For revegetation, it is suggested to plant trees which adapt to wet peatlands, or it’s so called paludiculture.
For revitalization, the communities shall get benefits from the peatland restoration, therefore, the plants or commodities for peatland restoration, shall be adaptable in the wet peatlands as well.

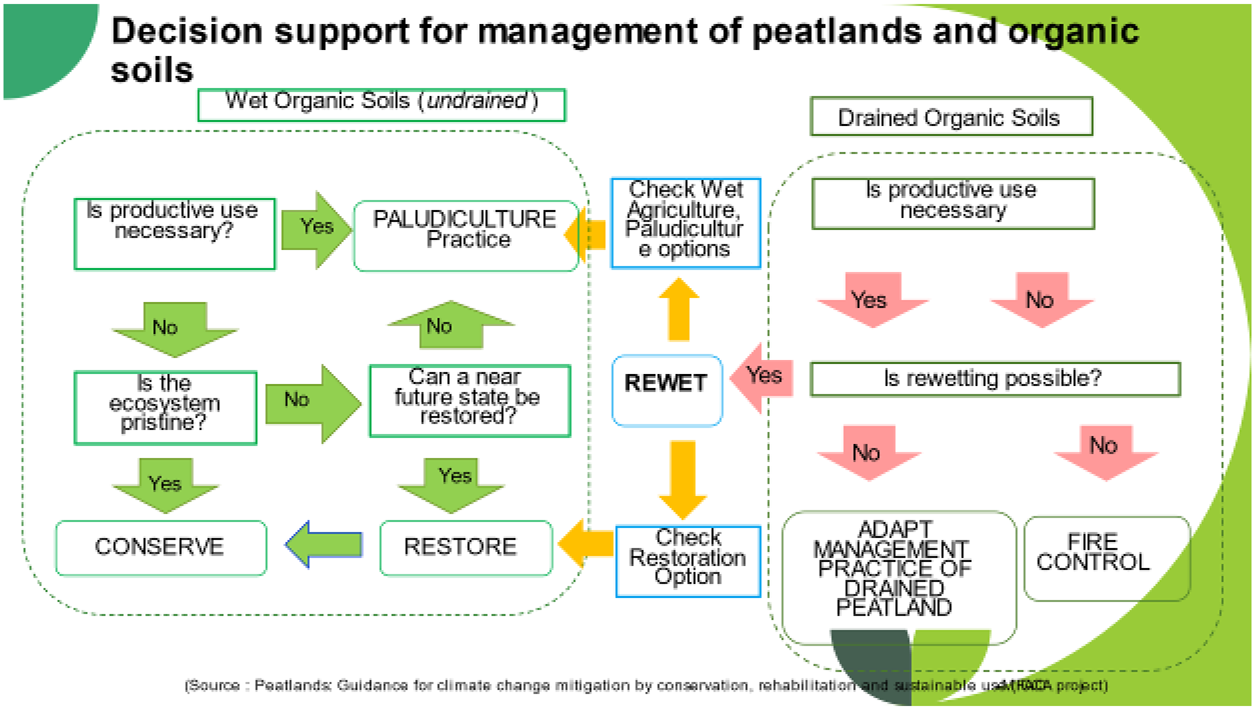


Definition and concept of paludiculture

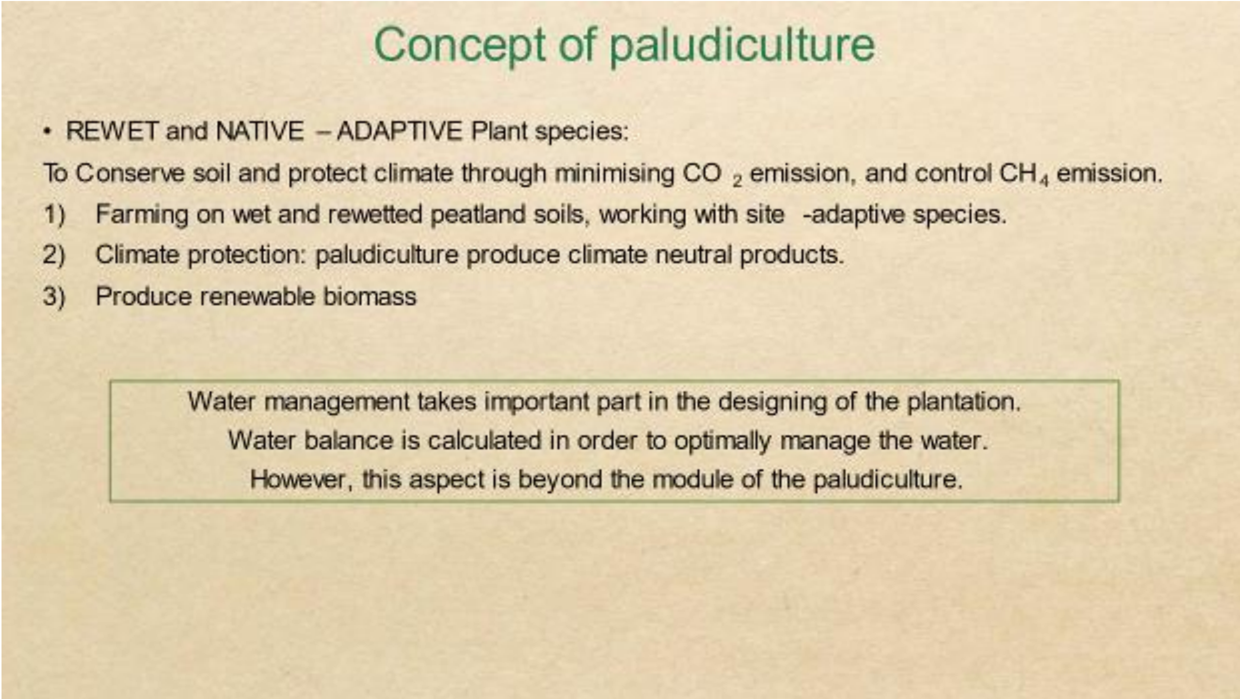


What is paludiculture? It derives from Latin words: “palus”, which means marsh. Literally, it defines as wet culture on marsh or peat-swamp.
We found two definitions of paludiculture. Paludiculture is defined as:

(1) Productive use of wet and rewetted peatlands in a way that the peat stock is long term preserved, by maintaining high water tables throughout the year (Whichtmann et al. 2016).
(2) An alternative of responsible peatland management (Biancalani & Avyagan, 2014)



The above diagram was adopted from Food and Agriculture Organization (FAO) book, shows decision support for management of peatlands and organic soils. In the left side is the condition of pristine peatland (undrained), while in the right side is the support systems of degraded peatlands (drained).
The degraded peatlands can be restored if rewetting is possible, otherwise, adapt the management practices of drained peatland and fire control.

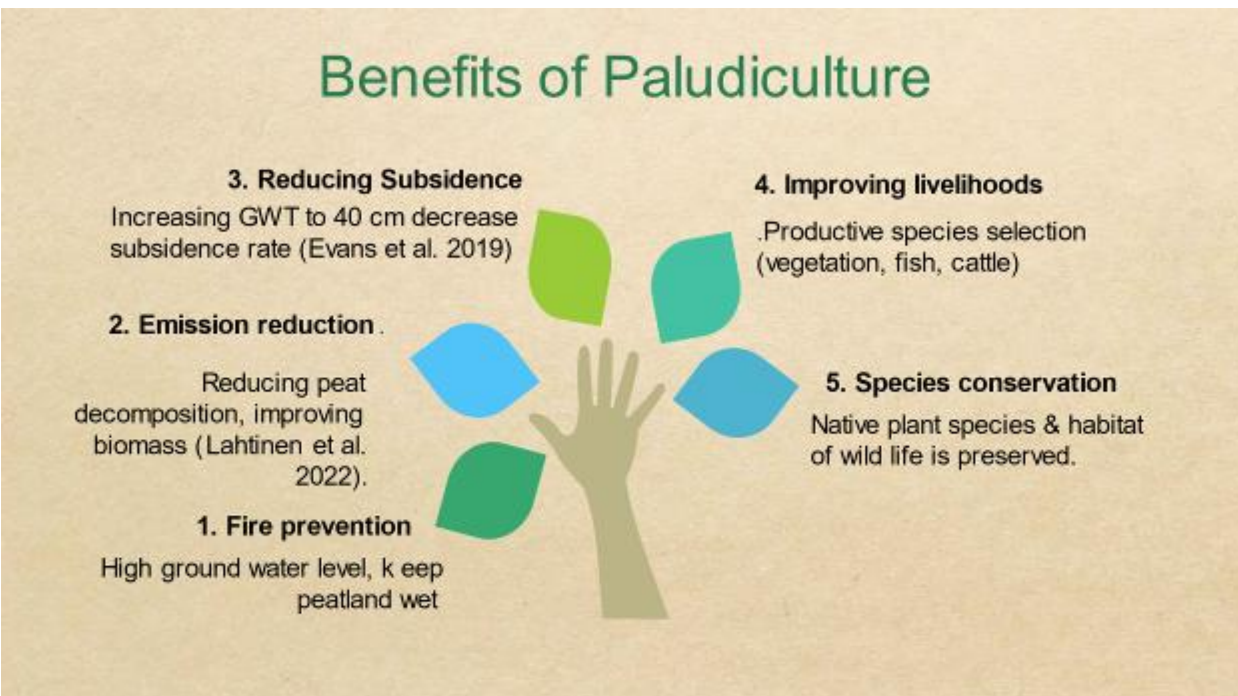


The concept of paludiculture is to conserve soil and protect climate through minimizing CO2 emission and control CH_4 emission.

1) Farming on wet and rewetted peatland soils, working with site adaptive species.
2) Climate protection: paludiculture produce climate neutral products.
3) Produce renewable biomass, replace conventional products.

Water management has important part in designing the plantation on peatlands, therefore, water balance needs to be calculated in order to optimally manage the water. However, please be noted that this aspect is beyond the paludiculture module.

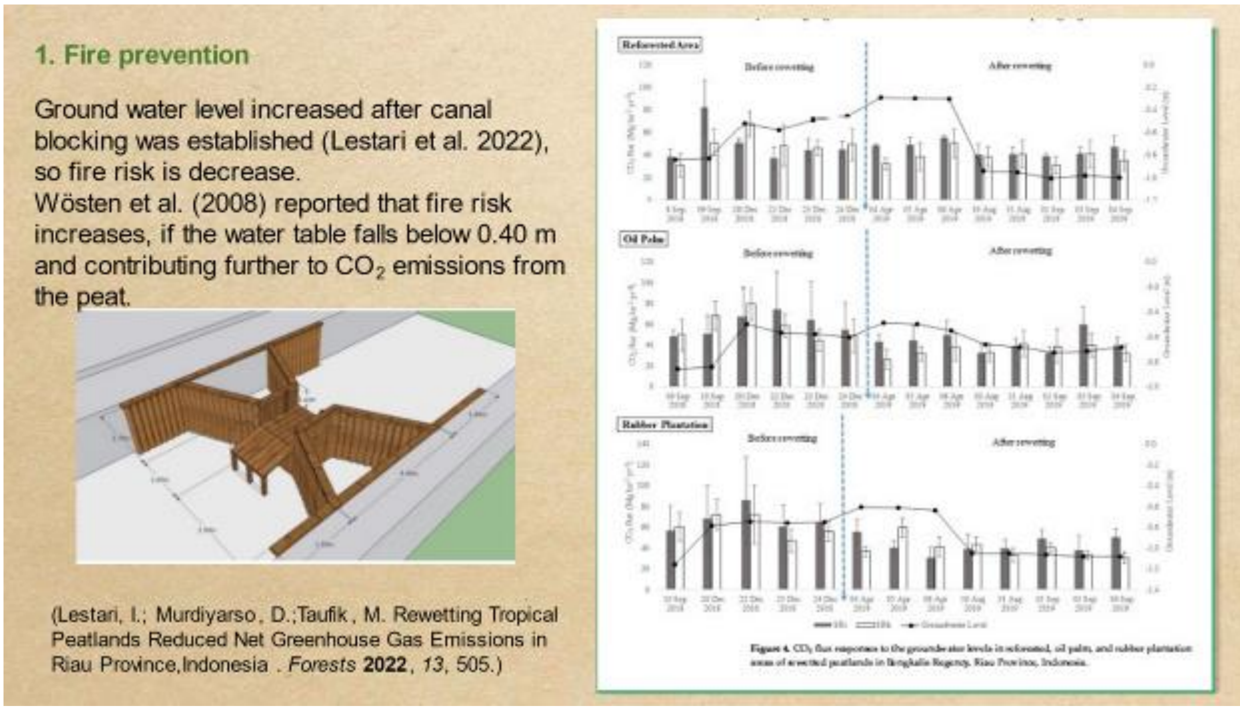
Paludiculture benefits.



We may get various benefits from paludiculture, such as:

1) Fire prevention: due to we maintain high ground water level, to keep peatland wet.

2) Emission reduction: by slowing down the decomposition, and improving biomass from vegetation.
3) Subsidence reduction: by increasing ground water table it will decrease subsidence rate.
4) Improving livelihoods: by species selection on paludiculture activities with productive and adaptive species (plants, fish, cattle, bees), it will increase livelihoods.
5) Species conservation: native species and habitats are preserved.



On the left side: The figure of canal blocking with spillway construction. The ground water level (GWL) increased after canal blocking has established. When the GWL falls below 0.40m, fire risk increased and contributing to CO_2 emission.
The figure on the right side is reported by Lestari et al. (2022). It shows GWL decreased after rewetting on three land use types of reforested area, oil palm and rubber plantations.

2. Emission reduction

Rewetting decrease ground water level (GWL) and CO_2 flux from total respiration and heterotrophic respiration (Lestari et al. 2022).

Table. Total net GHG emission expressed in CO_2eq in reforested area (RA), oil palm (OP), and rubber plantation (RP) before and after rewetting

Land Cover Type	CO_2		CH_4		N_2O		Total Net GHG Emissions	
	Mg CO_2-eq ha^{-1} yr^{-1}							
	Before Rewetting	After Rewetting	Before Rewetting	After Rewetting	Before Rewetting	After Rewetting	Before Rewetting	After Rewetting
RA	49.68 ± 6.84	45.18 ± 2.02	−19.67 ± 8.05	23.69 ± 8.02	31.20 ± 9.28	−17.17 ± 7.47	61.21 ± 8.07	51.70 ± 2.57
OP	55.71 ± 5.54	42.49 ± 3.18	10.32 ± 4.59	25.22 ± 17.27	39.52 ± 21.61	26.07 ± 14.41	105.55 ± 31.74	93.78 ± 34.86
RP	61.36 ± 7.28	41.48 ± 2.31	−16.03 ± 1.50	29.52 ± 10.58	98.60 ± 33.13	50.59 ± 20.05	143.93 ± 38.91	121.59 ± 32.94

(Source: Lestari et al. 2022)

Rewetting has also reduced CO_2 and NO_2 flux from total respiration and heterotrophic respiration at 3 land use types, as reported by Lestari et al. (2022). However, there was an increase on CH_4 flux emission, when GWL increased. So, it is important to do hydrology management on peatland restoration.

3. Reducing Subsidence

A study conducted at an acacia plantation in Riau showed that increasing GWT decrease subsidence rate (Evans et al. 2019)

Evans et al. 2019. Geoderma 338 (2019): 410 -421.

Plantation of Acacia crassicarpa in Riau

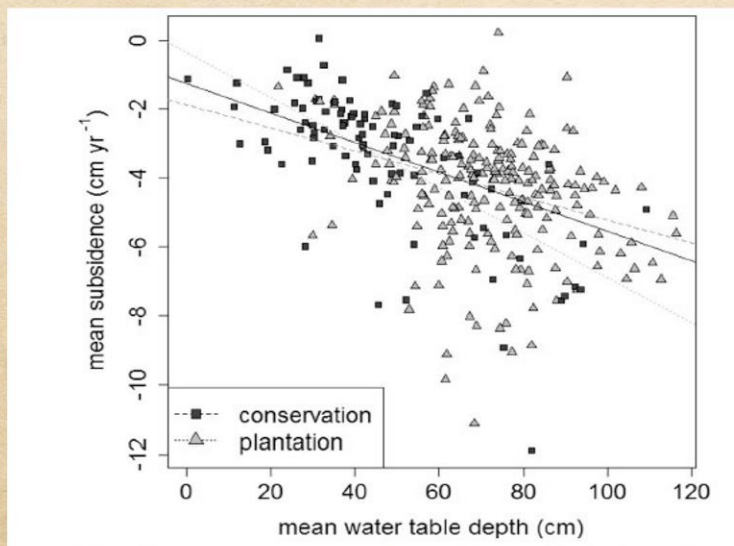


Fig. 2. Mean measured rate of subsidence and water table depth for all individual measurement sites. Solid line shows the best fit line of a linear regression fitted to all data (n = 318), short dashed line show fit to native conservation forest sites (n = 92) and long dashed line fit to *Acacia* plantation sites (n = 220).

A study conducted at an acacia plantation in Riau showed that increasing GWT decrease subsidence rate, as reported by Evans et al. (2019). Water table depth has negative relation with subsidence rate.

4. Improving livelihood

Productive species selection

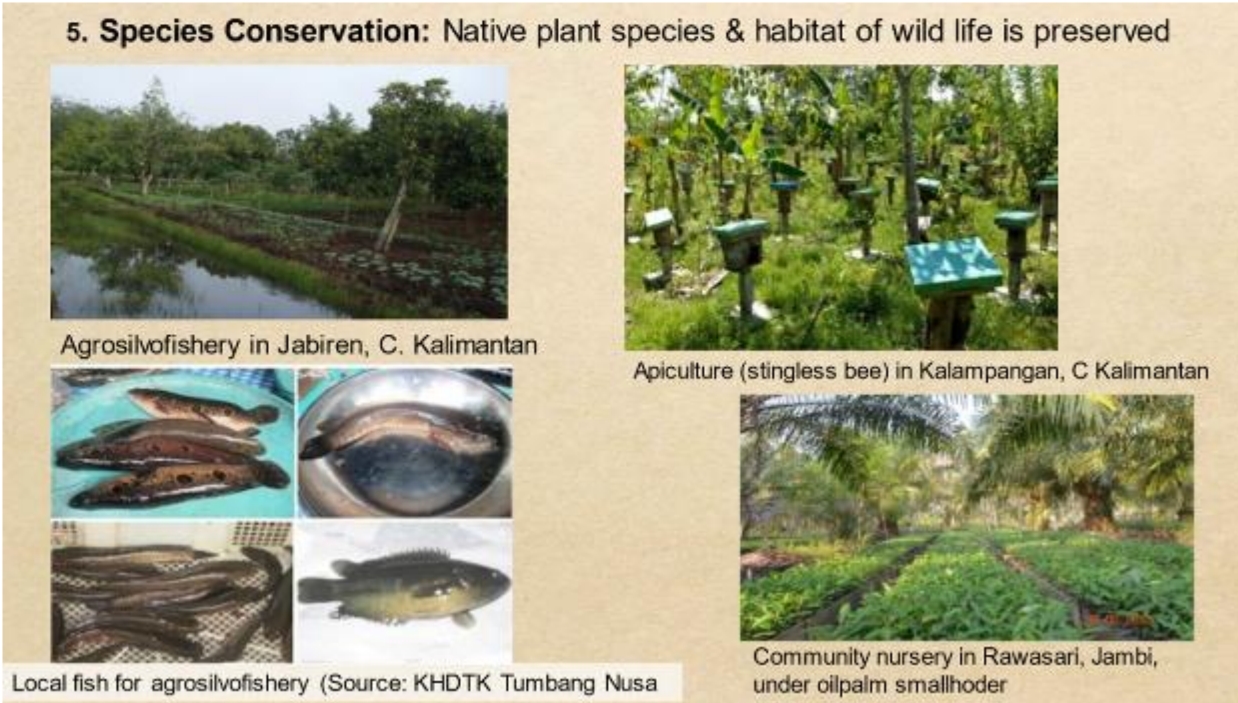
Commodities	Water table (m)	Estimated emission (t/ha/yr)	Estimated NPV (X1000 Euro/ha/25 yrs)
Illepenuts	0	0	10
Snakefruit	-0.2	20	25
Durian	-0.3	29	27
Liberica coffee	-0.5	49	29
Sweet melon	-0.3	34	29
Water spinach	0	9	32
Rambutan	-0.3	29	35
Sago palm	0	0	36
Kelakai	0	9	38
Pineapple	-0.3	34	38
Candlenut	-0.5	49	99
Dragon fruit	-0.3	34	110

(Source: Uda et al. (2020) Towards better use of Indonesian peatlands with paludiculture and low drainage food crops. Wetlands Ecology and management, 28: 509 -526)

Dragon fruit plantation in Msik, Central Kalimantan

Sago plantation in Selat Panjang, Riau

This table shows Net Present Values and estimated emission of some 'productive' plant species on peatlands in Central Kalimantan. It shows that only four plant species adaptable on high water table, and produce low estimated emission. The Net Present Values of some paludiculture species were considered as moderate, for example: Sago palm, kelakai (*Stenochlaena palustris*) and water spinach.



Paludiculture or wet-Agroforestry system as agrosilvofishery, apiculture can also conserve native species, not only plants, but also fish and local stingless bee.

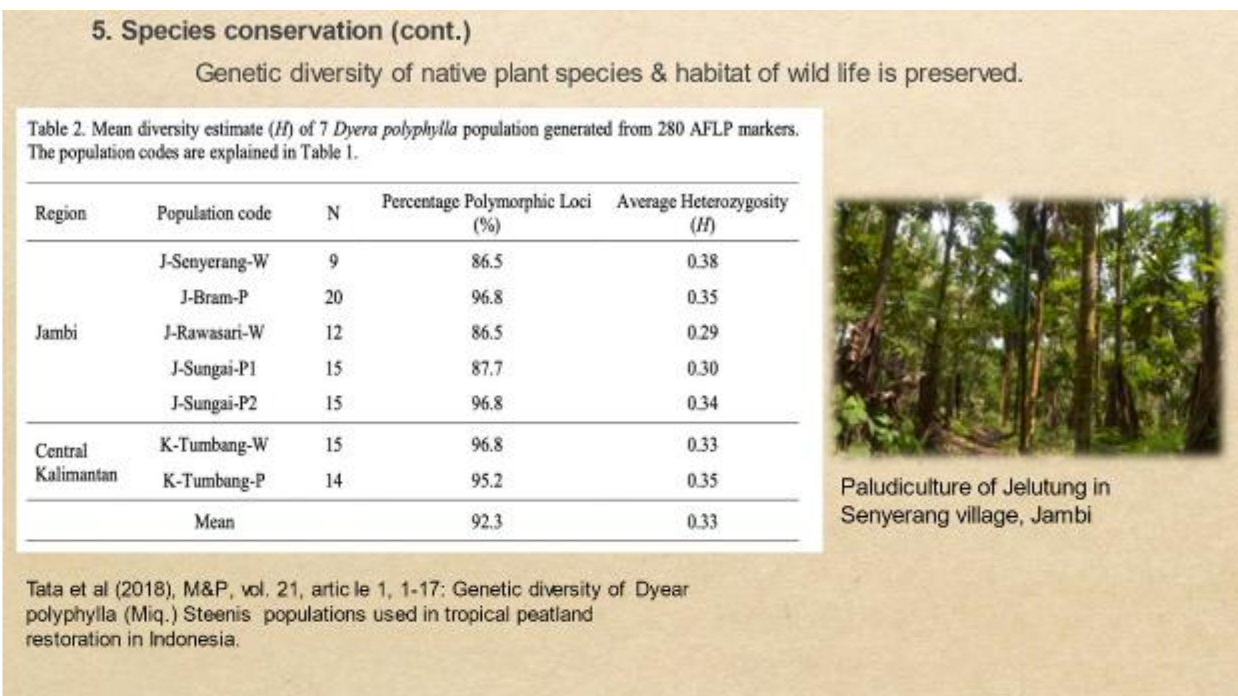


Table 2. Mean diversity estimate (*H*) of 7 *Dyera polyphylla* population generated from 280 AFLP markers. The population codes are explained in Table 1.

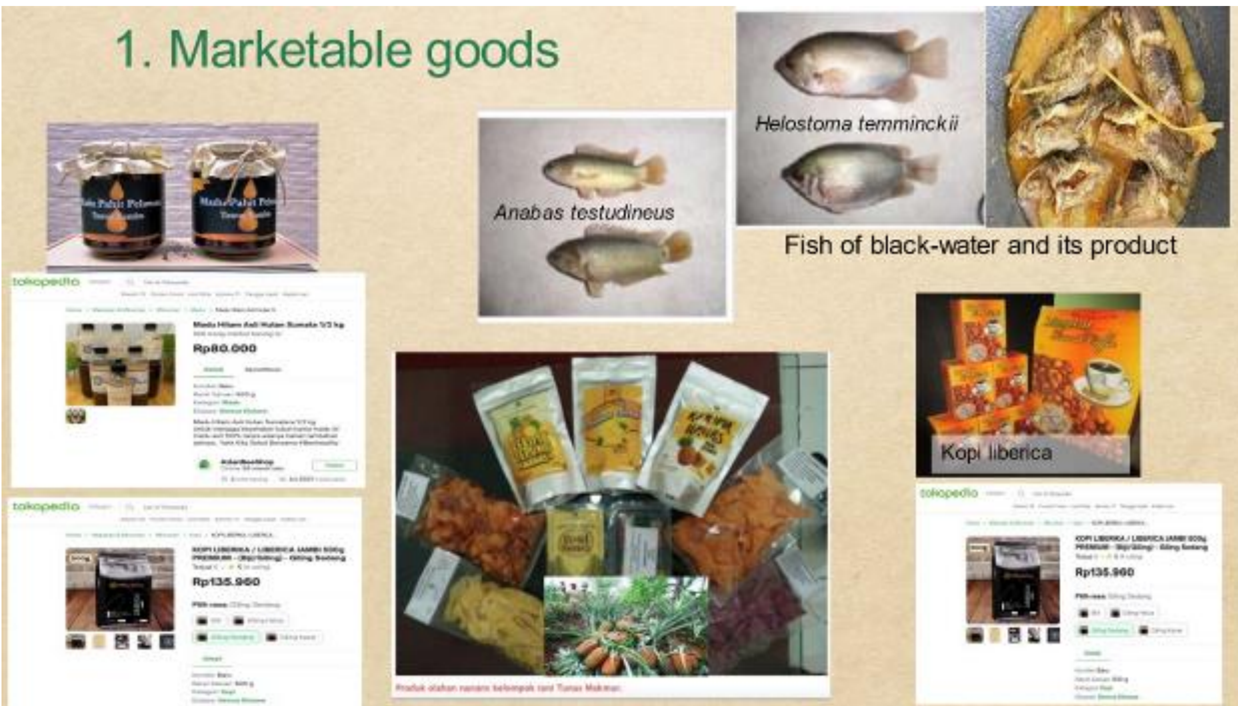
Region	Population code	N	Percentage Polymorphic Loci (%)	Average Heterozygosity (*H*)
Jambi	J-Senyerang-W	9	86.5	0.38
	J-Bram-P	20	96.8	0.35
	J-Rawasari-W	12	86.5	0.29
	J-Sungai-P1	15	87.7	0.30
	J-Sungai-P2	15	96.8	0.34
Central Kalimantan	K-Tumbang-W	15	96.8	0.33
	K-Tumbang-P	14	95.2	0.35
Mean			92.3	0.33

Paludiculture is not only conserve species diversity, but also genetic diversity, like for example jelutong (*D. polyphylla*). A wild population of jelutong in Senyerang village in

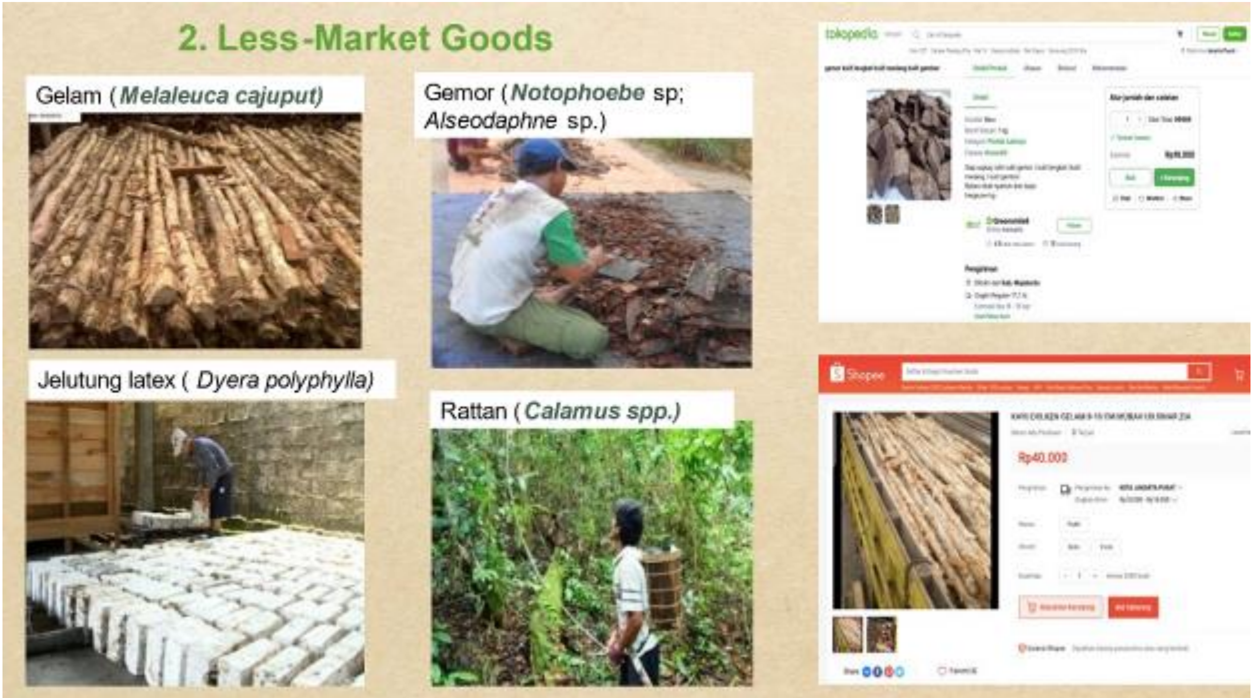
Jambi has the highest average heterozygosity compare to planted jelutong. Meanwhile, population of planted jelutong in a forested peatland, has close relation with jelutong from Central Kalimantan.

However, there is some challenges of paludiculture as well.

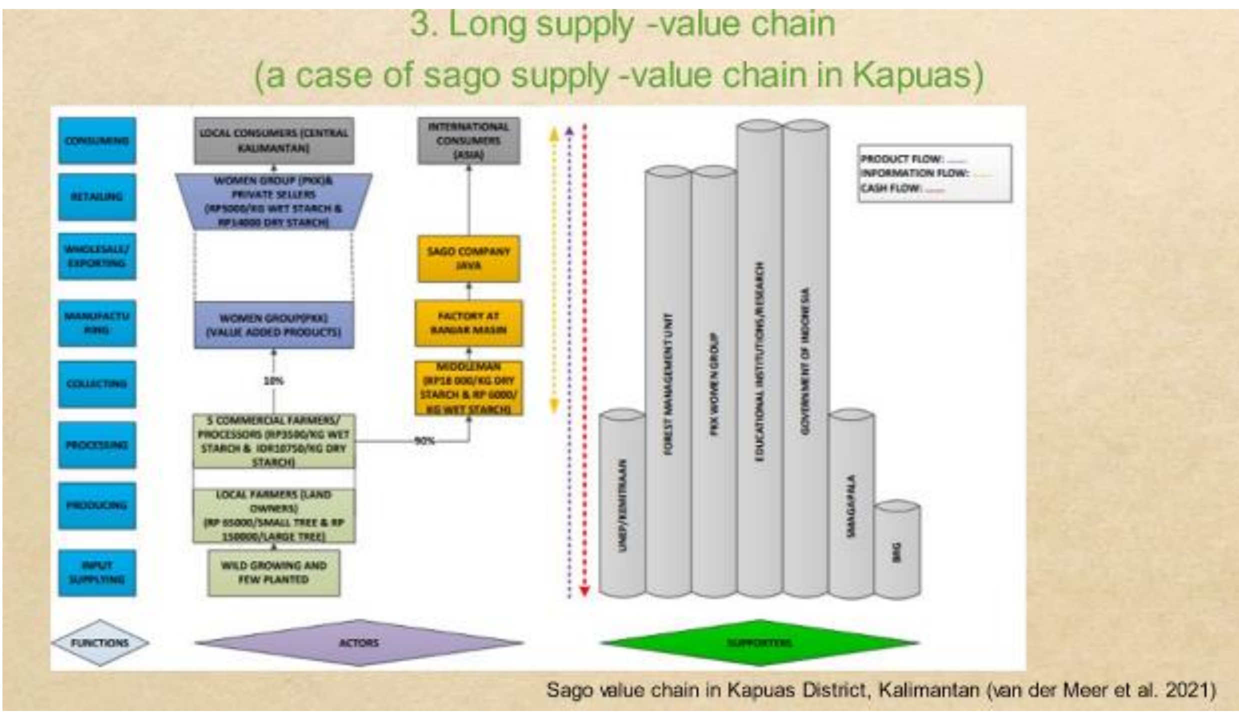
(1) Only limited marketable goods are available, such as sago, purun, gemor for mosquito repellent, gelam wood, and rattan.
(2) Less-marketable goods, such as latex/resin of jelutong, medicinal plants, illepe nuts, and timber
(3) Long value chain: from farmers to collectors, and have no market or limited to market access.
(4) Potential economic instrument, such as rewards for ES (fresh water), carbon market or carbon offset, and eco-tourism.
(5) Social inclusion: FPIC principles in every peatland restoration activity, communities engagement and stakeholders inclusion.



We can easily find in the market places sell products from peatland and peatland restoration activities. There are many edible products, such as black honey from Pelawan tree (*Tristaniopsis merguensis*), liberica coffee (*Coffea liberica*) and various peat and fresh water fish.



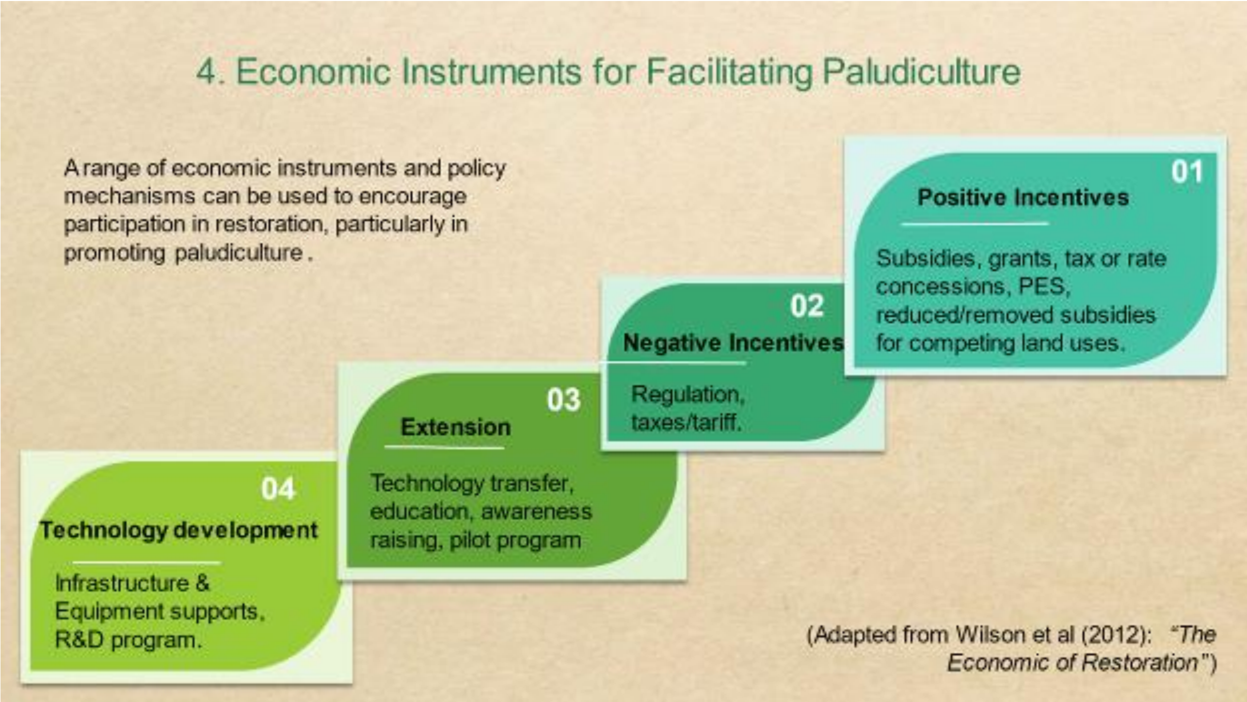
There are many paludiculture products which produce less marketable goods, such as gelam wood (*Melaleuca leucodendron*), latex of jelutong, bark of gemor (*Alseodaphne* sp. and *Notophoebe* spp.), and rattan (*Calamus caesius*).



Sago value chain in Kapuas District, Kalimantan (van der Meer et al. 2021)

A study has reported supply-value chain of sago in Kapuas district. It has long cash and information flow, from wild growing population and few planted, collectors, to the local consumers and international consumers.

This figure shows how long the supply-value chain of sago in Kapuas Central Kalimantan. Although sago has high commercial value, but the long supply value chain may increase the transaction cost and decrease profit of sago farmers as the basis of sago production.



To promote and improve paludiculture practice, a range of economic instruments and policy mechanisms can be used to encourage participation in restoration.

- Positive incentives, consists of subsidies, grants, tax or rate of concessions, PES, and reduced/removed subsidies for competing land uses.
- Negative incentives, consists of regulation and taxes/tariff.
- Extension, includes technology transfer, education, raising awareness, pilot program.
- Technology development, consists of infrastructure & equipment support, and R&D program.

Some cases of incentive scheme in peatland restoration in Indonesia

1. Canal blocking development and maintenance in Sebangau National Park, which includes: capacity building for local people, payment based on performance of canal blocking, and increasing water table.
2. Eco-tourism: the communities developed eco-tourism facilitated by The National Park, such as infrastructure, boats and capacity building on the management of community eco-tourism.
3. Incentives for 'purun' (*Lepironia* sp.) handicraft in South Kalimantan: equipment support and chanelling to market.
4. Development of smallholder sago in Kepulauan Meranti : technology development and infrastructure.

- Many stakeholders have taken part in paludiculture as part of peatland restoration.
- Only a few of them are aware of their potential role that can be contributed to the action.
- Social inclusion and community engagement in peatland restoration.
- The value of the interest of stakeholder is determined based on the 5 variables: perception, needs, motivation, forms of support and benefits expected by the parties in peat restoration.
- Applying Free Prior Informed Consent principle is a must. The local people engages in every step of the restoration activities.

In paludiculture, we must consider to plant the right tree species, which is adaptable to wet condition.

There are 1467 plant species of peat swamp ecosystem, but only 40% that have been recognize to have beneficial use. So, to develop paludiculture system, there are four principles of commodities selection, which consists of Environment friendly, economically benefit, technically applicable, and socially acceptable.

Like for example: what pant species can be planted as cultivation crops with sago? In Papua, people will be interested to plant 'buah merah', a Pandanus which produces red color fruits as traditional medicine. This species may not be a species preference in other area, because the others do not aware of 'buah merah'.

Growth and survival rate of some native plant species planted degraded peatland

Table 1

Species, height, growth and survival of the tree seedlings, Kalampangan experiments, mean height (±SD) at planting (H_0); height, growth % (compared to the planting height) and survival rate % after one year (H_1, Growth $\%_1$ and S $\%_1$); at the end of the measurement period ($H_{1.5}$); and two years after planting and immediately after fire damage (H_2).

Family	Species	Local name	N	H_0	H_1	Growth $\%_1$	S $\%_1$	$H_{1.5}$	Growth $\%_{1.5}$	S $\%_{1.5}$	H_2	Growth $\%_2$	S $\%_2$
Fabaceae	*Adenanthera pavonina*	Saga	107	14 ± 4	22 ± 6	55	89	31 ± 11	115	88			0
Meliaceae	*Aglaia rubiginosa*	Kajalaki	17	26 ± 7	35 ± 9	32	59	38 ± 12	45	59	46 ± 3	76	12
Lauraceae	*Alseodaphne coriacea*	Gemur	107	19 ± 4	24 ± 6	32	57	27 ± 7	46	54	34	84	1
Apocynaceae	*Alstonia pneumatophora*[a]	Pulai	108	17 ± 4	19 ± 5	13	36	18 ± 7	6	31	20 ± 7	20	6
Phyllanthaceae	*Baccaurea bracteata*	Hampuak	107	17 ± 4	24 ± 5	37	57	26 ± 7	49	46			0
Anacardiaceae	*Campnosperma squamatum*	Teras nyating	108	17 ± 4	20 ± 6	14	72	23 ± 8	31	44	26 ± 2	50	3
Apocynaceae	*Dyera polyphylla*	Jelutung	54	13 ± 4	16 ± 5	24	65	16 ± 5	25	50	20 ± 9	62	24
Burseraceae	*Dacryodes rostrata*	Keramu	108	42 ± 11	60 ± 18	41	87	65 ± 23	55	80	76 ± 18	80	21
Myristicaceae	*Gymnacranthera farquhariana*	Mandarahan putih	106	16 ± 5	22 ± 6	37	67	27 ± 10	68	63			0
Myristicaceae	*Horsfieldia crassifolia*	Mandarahan daun besar	106	20 ± 5	29 ± 8	46	80	38 ± 12	88	74	29 ± 16	44	3
Fagaceae	*Lithocarpus dasystachyus*	Pampaning	35	17 ± 3	35 ± 16	103	69	55 ± 30	220	57	44 ± 22	156	9
Sapindaceae	*Nephelium mangayi*	Rambutan hutan	52	27 ± 8	40 ± 12	50	52	39 ± 15	46	42			0
Meliaceae	*Sandoricum beccarianum*	Papung	36	23 ± 8	31 ± 10	36	69	35 ± 9	54	58	73	220	3
Dipterocarpaceae	*Shorea balangeran*[a]	Kahui	108	42 ± 9	76 ± 16	81	94	89 ± 21	113	94	49 ± 47	16	22
Species not included in the growth models													
Moraceae	*Artocarpus integer*	Mengkahai	108	48 ± 13	14 ± 9	−71	28	16 ± 15	−66	17			0
Malvaceae	*Durio* sp.	Durian	54	42 ± 8	48 ± 6	16	44	49 ± 7	17	22			0
Malvaceae	*Durio zibethinus*	Papaken	17	48 ± 12	48 ± 13	−1	35	39 ± 7	−20	24	32	−34	6
Sapotaceae	*Palaquium leiocarpum*	Hangkang	54	13 ± 6	16 ± 5	24	24	20 ± 6	56	20			0
Myrtaceae	*Syzygium* sp.	Jambu	105	29 ± 7	32 ± 8	12	40	31 ± 8	9	24			0
Malvaceae	*Sterculia* sp.[b]		91	23 ± 6	32 ± 13	39	71	36 ± 15	57	60			0
		Talum putih[c]	108	16 ± 6	31 ± 14	101	92	40 ± 20	156	92			0

[a] 20 seedlings from each these species were removed at the end of the measurements period (1.5 years); survival % calculated from the remaining number of seedlings (88).
[b] Species unclear, genus *Sterculia*.

(Source: Lampela et al. (2017) Promising native tree species for restoration of deraded tropical peatands. Foreco, 394, 52 -63)

Many initiatives of peatland restoration have been conducted in Indonesia and planted native peatland plant species, especially in the revegetation aspect. This table shows you the growth and survival rate of 15 native peatland species, compare to 6 non-native peatland species, which are commonly planted by local people on peatlands in Central Kalimantan.

Here we see, the highest survival rate is *Shorea balangeran* (kahui), which is native peatland species. While for non-native peatland species, *Sterculia* sp. had the highest survival rate up to 1 year after planting.

Some commercial species in Indonesia

Rotation type	Species alternative	Economic values	Location
Short (6-12 months)	Purun grass (*Lepironia articulata*) Vegetables: spinach water (kangkong), Stingless bee (Trigona spp.)*	High High High (Honey: IDR 175.000/kg)	C. Kalimantan, S. Kalimantan, S. Sumatra Riau
Long (>1 yr)	- Sago (*Metroxylon* spp.) - Gelam (*Melaleuca leucodendra*) - Cajuput (*Melaleuca cajuputi*) - Meranti (*Shorea balangeran*) - Jelutung (*Dyera polyphylla*) - Gemor (*Alseodaphne*, *Notophobe*)	Benefit: $500/ha/ yr Price: IDR 8000 – 55.000/pole Cajuput oil: IDR 240,000/kg Meranti Wood No transparent market available No transparent market available	Riau, C. Kalimantan C. Kalimantan C. Kalimantan C. Kalimantan, S. Sumatra Jambi, S. Sumatra, C. Kalimantan S. Sumatra, C. Kalimantan
Potential species	- Tumih (*Combretocarpus rotundatus*) - Terentang (*Campnosperma* sp.) - Nyatoh (*Palaquium* sp.) - Punak (*Tetramerista glabra*) - Gerunggang (*Cratoxylum* sp.) - Medicinal plant species: bawang Dayak (*Eleutherine bulbosa*), akar kuning (*Fibraurea tinctoria*), rambai (*Baccaurea* spp.)	Pioneer species, fuel wood Timber, pulp Latex Timber Timber, pulp Medicine	S. Sumatra (Punak) C. Kalimantan (all listed species)

We can classified some commercial paludiculture species in Indonesia based on rotation types:

1. Short rotation (6-12 month), consisted of purun grass, spinach water and stingless bee.
2. Long rotation (> 1 year), such as sago.
3. Potential species: such as: *Combretocarpus rotundatus* (tumih), *Tetramerita glabra* (punak), *Eleutherine bulbosa* (bawang Dayak).

Some photos of paludiculture species are shown in this figure.

Two plant species are presented as example of paludiculture species, and its business model.

Sago at Sungai Tohor, Riau

- Habitat: swamp and peat swamp (shallow to moderate peat depth; GWL <=50 cm.
- Distribution: Sumatra (Riau, Jambi), Java, Sulawesi, Kalimantan, Mollucs and Papua.
- Cultivation: generative dan vegetative. Planting space: 8m x 8m.
- Sago at Sungai Tohor, Riau: in monoculture plantation and industry has been developed.
- Waste management should be taken seriously, as all part of sago can be processed.

Economic value and Environmental benefit of sago

NPV of several commodities, and CO_2 emission from biomass loss or peat decomposition at several land use types

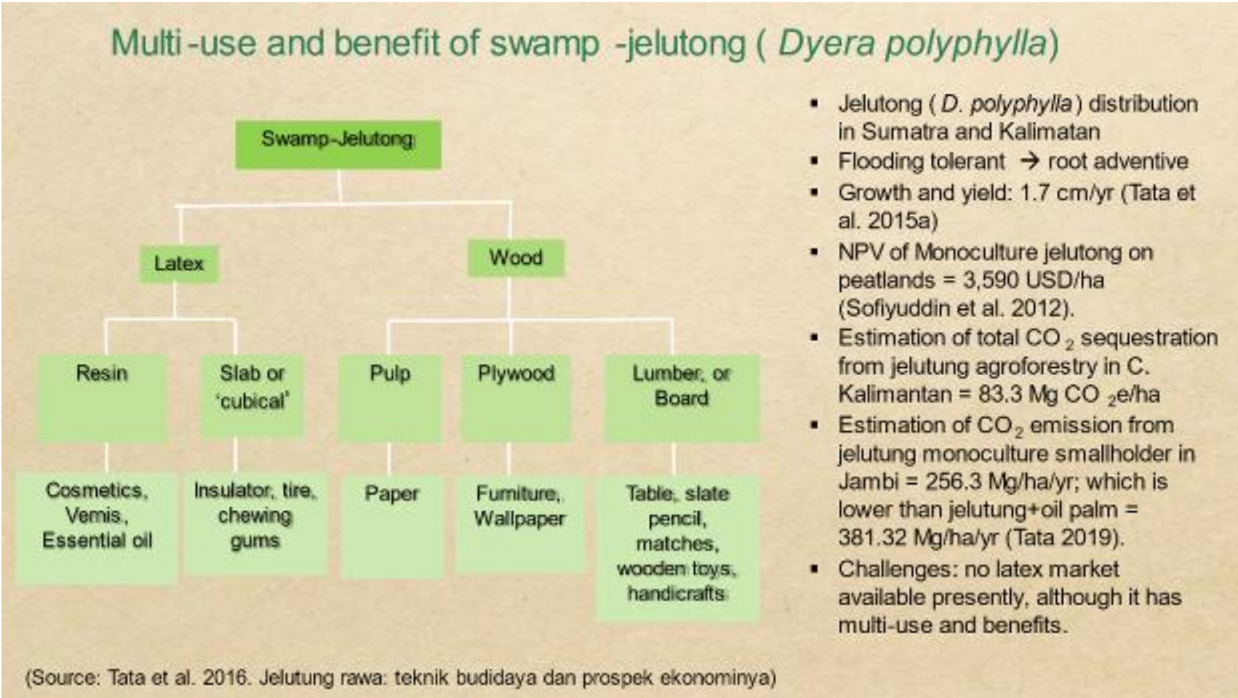
Location - Commodity	Jambi (Oil Palm 6 yrs)	Riau (Oil Palm 6 yrs)	C. Kalimantan (Rubber 5 yrs)	W. Kalimantan (Corn)	Papua (sago forest)
NPV (USD/ha/yr):*					
	827	2515	4081	291	441
Emission from biomass loss and peat decomposition (Mg CO_2/ha/year):					
Peat Shrubs	19.6	22.8	30.8	10.6	-15.4
Secondary peat swamp forest	37.9	62.5	49.1	62.8	3.0
Primary peat swamp forest	63.3	87.9	74.5	88.2	28.4

(note: * interest 10%; 1 USD = Rp 13,000)

(Source: Agus et al. 2016)

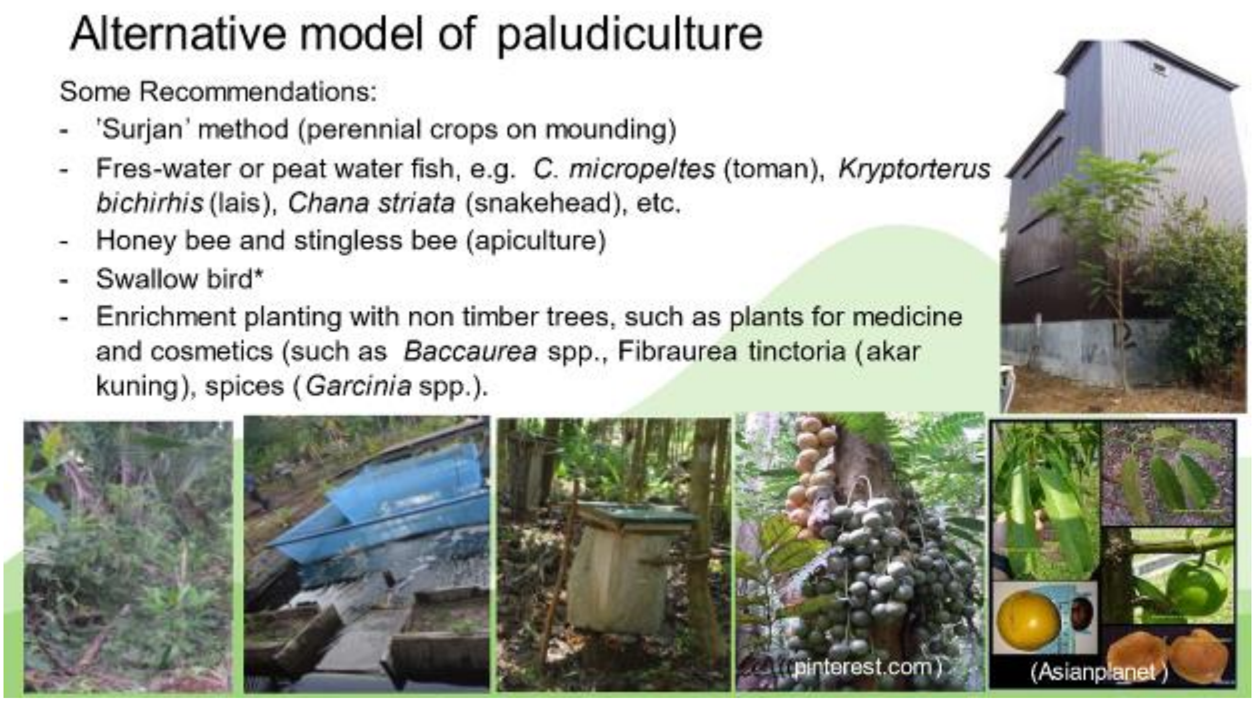
- NPV of sago noodle at Tebing Tinggi: IDR 444,6 millions (Mukti & Elida, 2017)

Table above shows the economic value and environmental benefits of sago plantation in Papua.
Net Present Value (NPV) of sago was 441 USD/Ha/Yr, while the emission from biomass loss and peat decomposition of sago, varies between -15.4 Mg CO_2/ha/yr, when sago was derived from peat shrubs, up to 28.4 Mg CO_2/ha/yr, when sago was derived from primary peat swamp forest (Agus et al. 2016).



The case of Jelutung: multi use and benefit.
Jelutong can produce various products, from latex and its woods. As raw material for cosmetics, essential oil, up to paper and furniture.

NPV of jelutong was reported was USD 3,590 USD/ha (Sofiyuddin et al. 2012). Estimation of CO_2 emission in the smallholder jelutong monoculture in Jambi was 256.3 Mg/ha/yr, while estimation of CO2 sequesttration from eluting agroforestry in Central Kalimantan was 83.3 Mg CO_2e/ha.



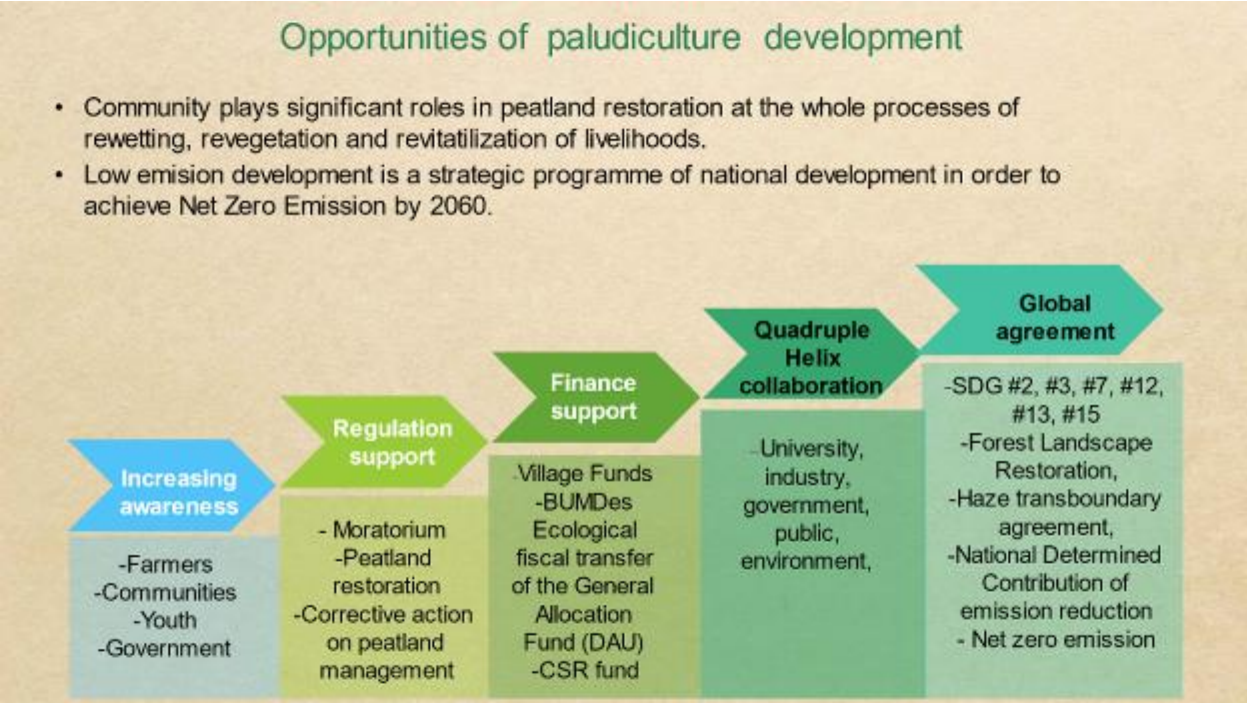
There some alternative model of paludiculture, such as:

- 'Surjan' method (perennial crops on mounding)
- Fres-water or peat water fish, e.g. *C. micropelets* (toman), *Kryptorterus bichirhis* (lais), *Chana striata* (snakehead), etc.
- Honey bee and stingless bee (apiculture)
- Swallow bird*
- Enrichment planting with non timber trees, such as plants for medicine and cosmetics (such as *Baccaurea* spp., Fibraurea tinctoria (akar kuning), spices (*Garcinia* spp.).

There are three steps to get green production market from paludiculture:

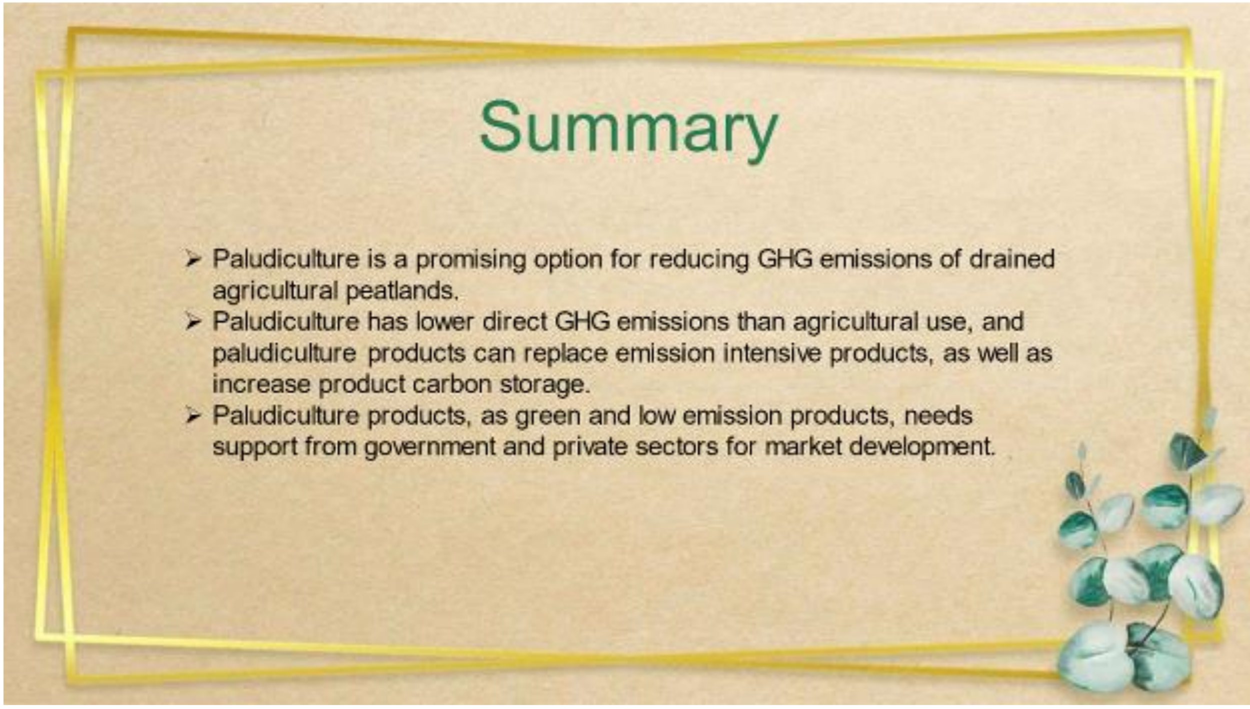
1. Sustainable paludiculture: which apply sustainable on-farm, implementing hydrology concept, peatland friendly commodities, intercropping with conservation plantation

2. Operationalized local institutions: includes improving & strengthening local farmer groups, Professionalized village enterprise, synergy with government program, operationalized center of excellence.
3. Improve market and market access: which consists of improve value chain, established peartnership with private sector, carbon project, juridisional support from government.



Community plays significant roles in peatland restoration at the whole processes of rewetting, revegetation and revitatilization of livelihoods.
Low emision development is a strategic programme of national development in order to achieve Net Zero Emission by 2060.

The paludiculture development consists of:
1. Increasing awareness
2. Regulation support
3. Finance support
4. Quadruple helix collaboration
5. Global agreement.



- Paludiculture is a promising option for reducing GHG emissions of drained agricultural peatlands.
- Paludiculture has lower direct GHG emissions than agricultural use, and paludiculture products can replace emission intensive products, as well as increase product carbon storage.
- Paludiculture products, as green and low emission products, needs support from government and private sectors for market development.

This is end of the Module 1B.